

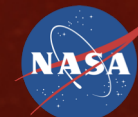
Charting a Course to the Sun: Flight Path Control for Parker Solar Probe



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January 14, 2019

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Government sponsorship acknowledged



Agenda



- **Parker Solar Probe Mission Overview**
 - **Spacecraft Configuration**
- **Baseline Reference Trajectory**
 - **Maneuver Locations and Strategy**
 - **Pre-launch Analysis**
- **Operations Experience**
 - **Launch and TCMs 1-6**
- **Summary and Upcoming Activities**

Overview of Mission



- **Parker Solar Probe (PSP) Project managed by Johns Hopkins Applied Physics Laboratory (APL)**
 - Builds and tests the spacecraft
 - Provides
 - Flight Operations team
 - Mission Design and trajectory correction maneuvers (TCM) management
 - Designs the reference trajectory
 - Guidance and Control team
- **NASA Jet Propulsion Laboratory (JPL) - Navigation Services**
 - Provides orbit determination and spacecraft trajectory predictions
 - Works with APL Mission Design to plan and generate TCMs
 - Releases final reconstructed spacecraft trajectory

Overview of Mission



■ PSP Science Goals

- Trace the flow of energy that heats the corona
- Determine the mechanisms that accelerate and transport energetic particles
- Explore dust plasma near Sun
- Determine structure and dynamics of magnetic fields at the sources of solar wind

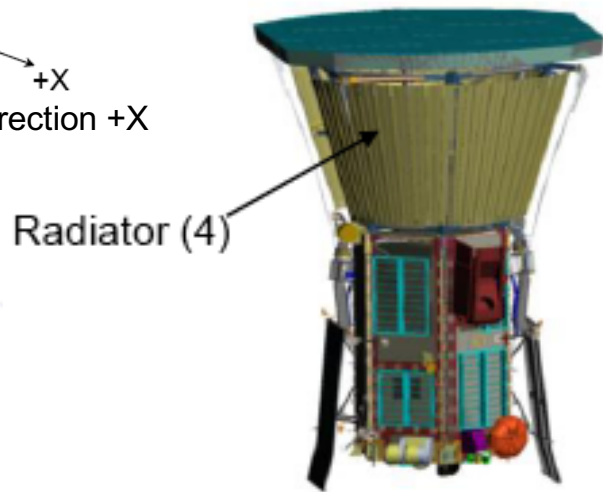
■ PSP Instruments

- Fields Experiment (FIELDS)
- Integrated Science Investigation of the Sun (ISIS)
- Wide-field Imager for Solar PRobe (WISPR)
- Solar Winds Electrons Alphas and Protons (SWEAP)

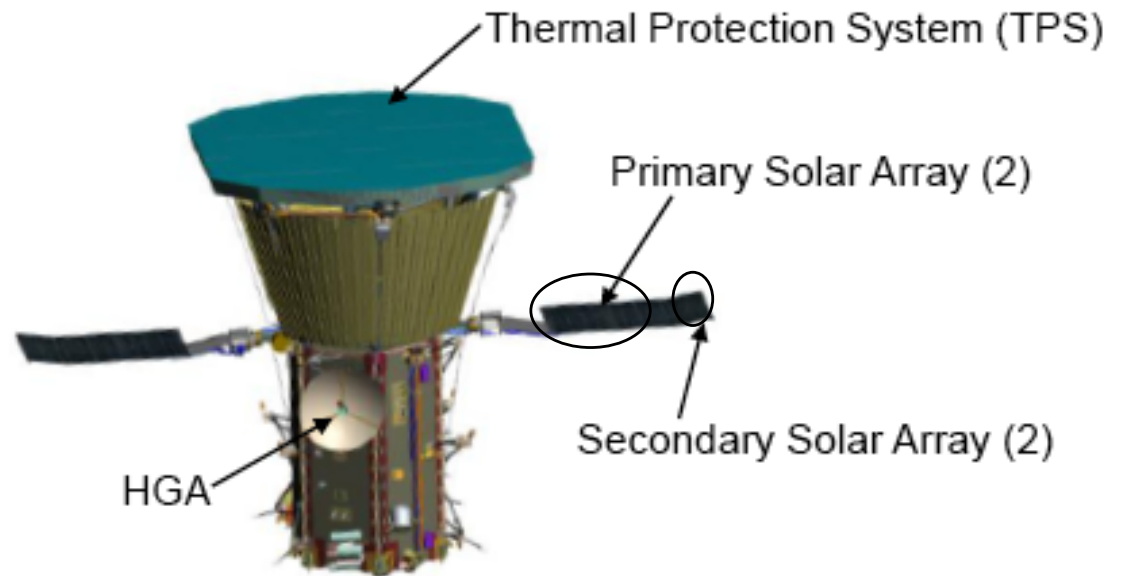
Spacecraft Configuration



+Z
+Y
+X
Ram Direction +X



S/C Configuration Near Sun



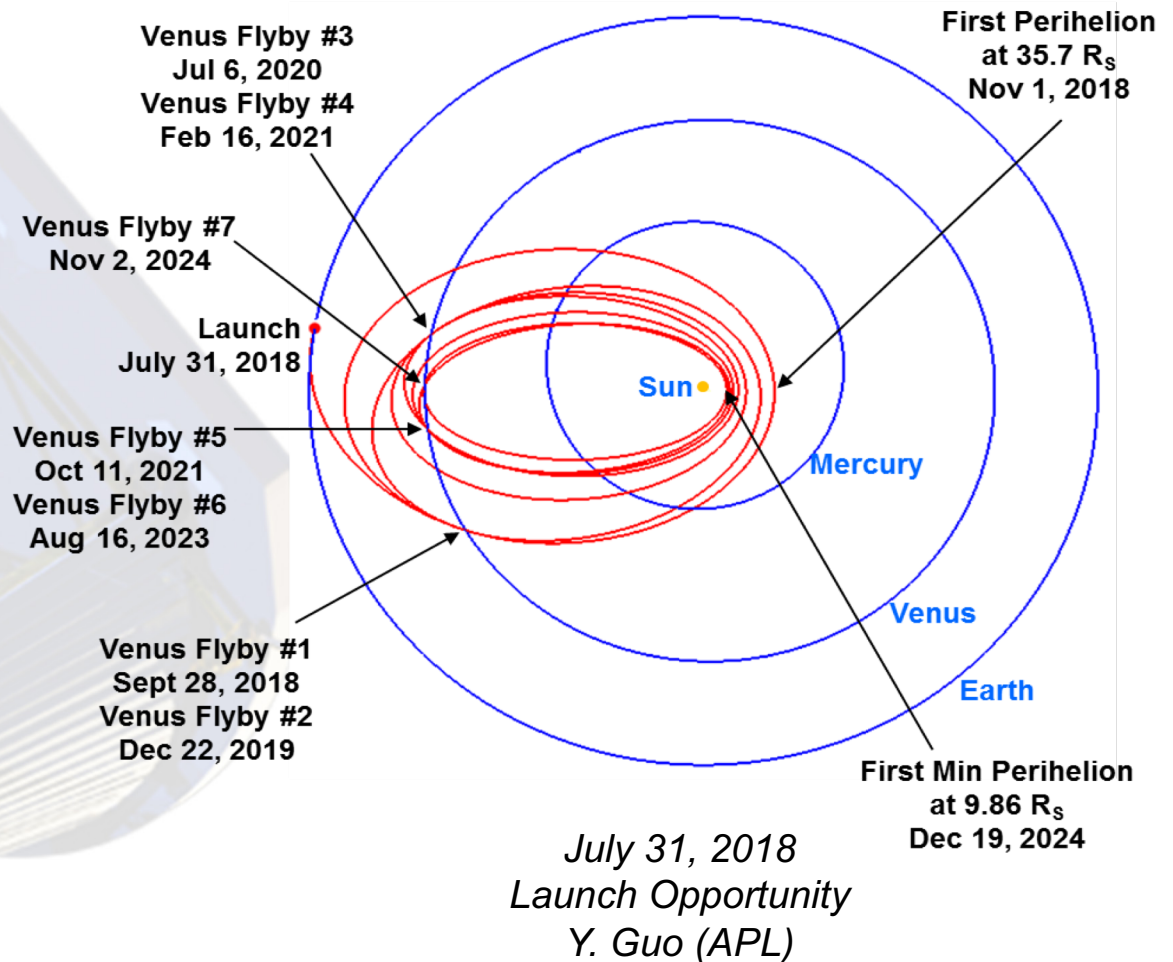
S/C Configuration Near Earth

- **Spacecraft is 3-axis stabilized**
- **Thermal Protection System pointed at the Sun**
- **Primary Array – photovoltaic arrays used outside 0.24 AU**
- **Secondary Array – used through closest approach**
 - **Array with pumped-fluid cooling to maintain operating temperature**

Reference Trajectory



- **Provided by APL**
- **Baseline Trajectory**
 - **Launch Period**
 - July 31- Aug 23, 2018
 - **Delta IV Heavy**
 - **Ballistic – no deterministic maneuvers**
 - **Seven Venus flybys**
 - **Total mission time: 7 years**



Maneuver Locations



■ Control

- Perform cleanup maneuver quickly after launch
- Two TCMs target to upcoming encounter
- One TCM is a post-encounter cleanup
- Whenever possible, added additional TCM per orbit
- One TCM targets solar periapsis after final Venus flyby
 - Trajectory requirement

■ Constraints

- Trajectory optimization
 - Venus flybys no lower than 300 km
- Several tracking gaps for every trajectory
 - Result of unique trajectory geometry
- Power and thermal limitations
 - Maneuvers not scheduled inside 0.45 AU from Sun
 - Maneuvers outside 0.82 AU implemented with 45 degree Sun ΔV angle constraint (cone keep out)

Maneuver Strategy



- **Baseline Trajectory: Total of 42 TCMs**

- **39 TCMs used to target Venus-1 through Venus-7 encounters**
 - TCMs are optimized in “chain”
- **3 TCMs post-Venus-7 flyby**
 - Each TCM targets the next upcoming solar periapsis

- **Mission Design and Navigation Requirements**

- **Imposed as constraints in simulation set-up**

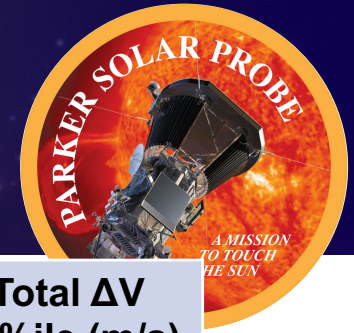


Pre-launch Analysis



- **Launch Period - July 31, 2018 to Aug 23, 2018**
 - Added four days
- **Two design cycles performed within the year before launch**
 - Refined navigation assumptions, high-fidelity models
 - Updates to tracking schedules
- **Reviewed TCM and targeted flyby locations**
 - TCMs could either be inside or near communication tracking gaps
 - TCM-18: removed from strategy for the final 10 trajectories
 - August 14 – 23

Statistical Results



- MONTE-LAMBIC software was used to compute statistical ΔV via Monte Carlo analysis
- Table shows statistical results for all 24 FMA reference trajectories
 - Used middle-of-window Injection Covariance Matrix
- Results satisfy MDNR-22: Statistical ΔV (Baseline)
 - Total $\Delta V_{99} \leq 135$ m/s
 - TCM-01 $\Delta V_{99} \leq 60$ m/s
- Note: Level of statistical uncertainty in the total ΔV_{99} is ~3-5 m/s

FMA reference trajectory	TCM-01 ΔV 99%ile (m/s)	Total ΔV 99%ile (m/s)
180731	32	69
180801	33	68
180802	34	69
180803	34	69
180804	34	69
180805	34	70
180806	33	71
180807	34	72
180808	33	73
180809	34	72
180810	34	72
180811	33	71
180812	35	75
180813	35	75
180814	35	99
180815	34	78
180816	35	91
180817	34	81
180818	34	88
180819	34	99
180820	35	87
180821	36	82
180822	34	85
180823	35	82

Operations Experience



■ Launch

- Successful on Aug 12, 2018
- Delta IV Heavy with Star-48BV third stage

■ TCMs 1-6

- Mission design and flight path control teams exercised several TCM design strategies
 - Nominal
 - Contingency
 - Cancelled
- In-flight analysis considers downstream maneuver costs

TCM Experience: Predicted vs Designed



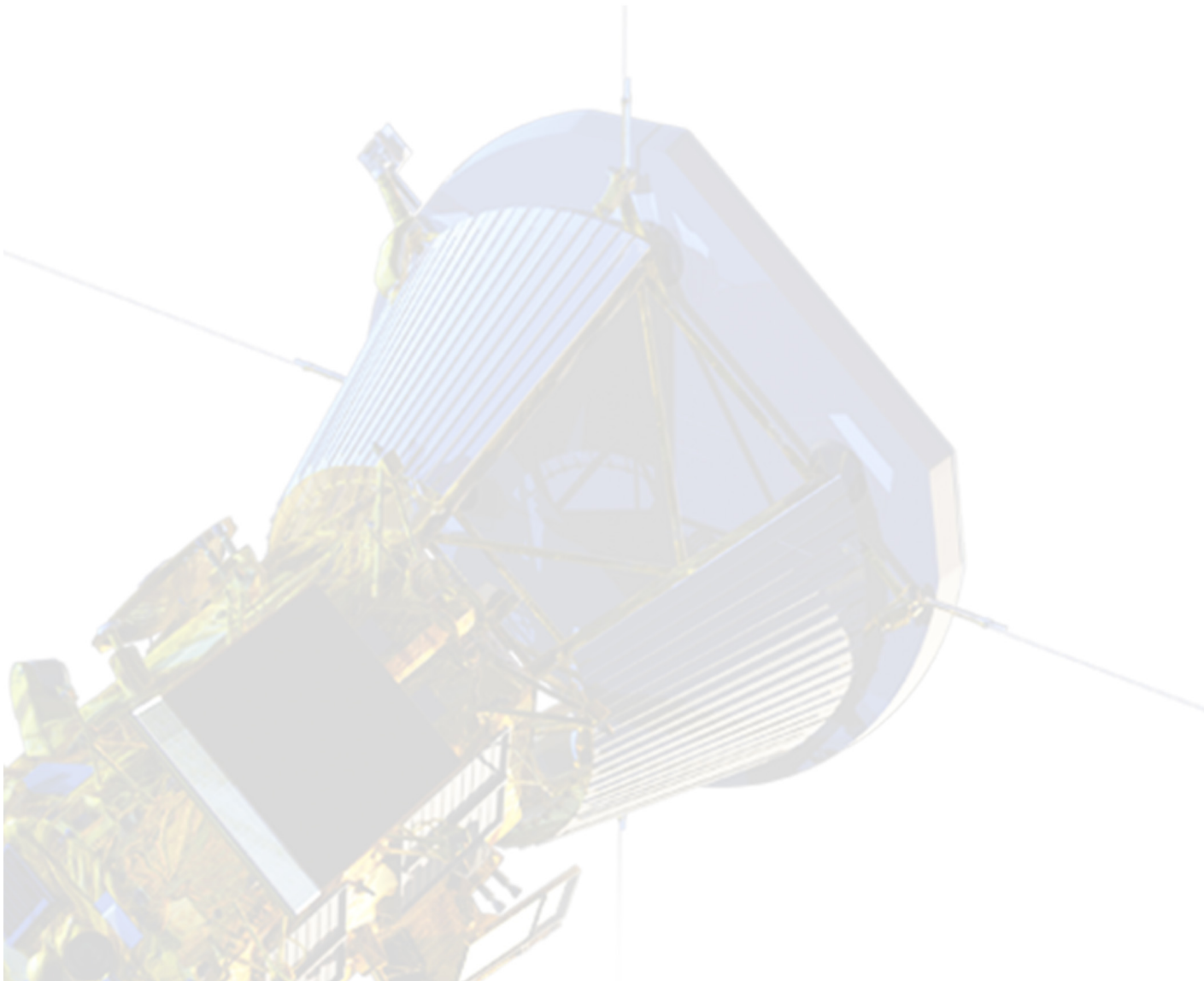
Event	Predicted ΔV Statistics			Design ΔV
	Mean	1-sigma	ΔV_{99}	
<i>Launch</i>	--	--	--	--
TCM-01 and TCM-01c	12.75	6.95	34.59	10.23
TCM-02	0.19	0.14	0.66	0.734
TCM-03	0.004	0.018	0.086	Cancelled
TCM-04c	0.051	0.049	0.18	0.069
<i>Venus-1</i>	--	--	--	--
TCM-05	0.824	0.95	4.03	Cancelled
<i>Perihelion-1</i>	--	--	--	--
TCM-06	0.405	0.272	0.92	1.10

Summary and Upcoming Activities

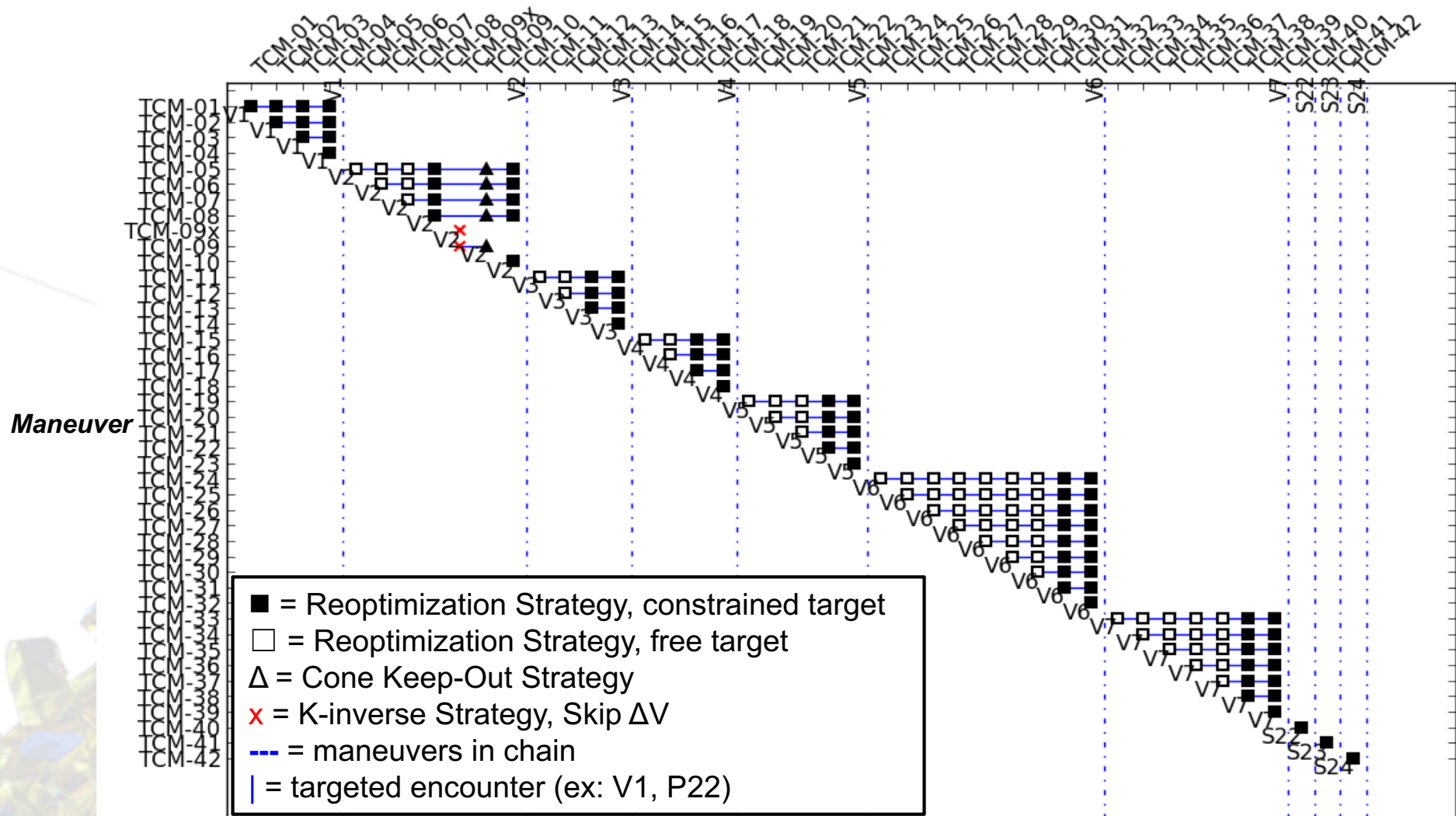


- **Within the four months since launch**
 - Performed four TCMs
 - Cancelled two TCMs
 - Venus-1 flyby on October 3, 2018
 - First solar periapsis on November 6, 2018
- **Downlink of Science Data started on 7 with initial findings presented at 2018 American Geophysical Union**
- **Mission design and flight path control teams exercised several TCM design strategies**
 - Will prepare for upcoming events
 - TCM-7 - May 13, 2019

Backup



Targeting Strategy



Downstream Maneuver(s) used in “chain” in Lambic optimization strategy